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Theoretical and Experimental Investigation on a Single Basin Double Slope Solar Still

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ABSTRACT

Solarstill,whichconvertsavailablebrackishor impurewaterinto potablewater,canbeusedtosupplydrinkingwaterforthepeoplelivingin arid andremote areas. But, thisstill isnot popular because of its lower productivity. This research work presents the theoretical and actual performance ofthe single basin double slope solar still and explores the differentmethodstoimprovetheefficiency.

Asinglebasindoubleslopestillwithoverallsizeof2.5m 1.5m 1m wasfabricated and tested under laboratory conditions (*still – laboratory*)andinactualsolarradiationconditions(*still –solar*)at chidambaram(9^{O}11'N,77^{O}52'E),acity insouthernIndia.Experimentswereconductedfor different depthsofwaterupto0.2cmandwithdifferent basinmaterials. Differentwickmaterialslikelightcottoncloth,juteclothandlightsponge sheetwereused.Aluminiumrectangularfinsarrangedinlengthandbreadth wisecoveredwithcottonclothandjuteclothwere alsousedinthe basin.The solidmaterialslikequartziterocksof differentsizes,naturallywashedstones, cementconcretepiecesand,brick piecesand ironturningswereusedinthe basin.Theabovesaidsolidmaterialswerenotusedsofar. Experiments wereconductedusingdifferentglassthicknesswith differentinclinationandorientationandthe variationsintransmittancewere studied.Aregressionequationwasestablished,to calculatethetransmittance ofthegiventhickness glassplate atanyplace andatanytimeforgiven radiation conditions. The variationsofenergy losses at cover plates were studied.

A new model is proposed for the theoretical analysis by considering the transmittance variations ofthe cover plates and radiation received at the glass cover as input. In theearlier work, constant transmittancewasconsideredandradiationonthe horizontalbasinareawas considered as input. From thetheoretical analysis of the still (*still – theoretical*)usingproposedmodel,it wasfoundthat,thestillproductionwas increasingwiththedecreasein depth.Inadditiontothestudyof variationsof watertemperature,glasstemperatureand productionrate withlocaltime,the variation *of water – glass temperature difference with local time and production rate*were alsostudied.Atlowbasin watertemperature, below 60^{O}C,water–glasstemperaturedifferencewashavingproportionatevariation with productionrate. At higherwater temperature above 60^{O}C, the still behaviorwasdifferentandthe productionratevariedinverselywiththis temperature difference. During this different operation condition, the productionratewas

high.Thisdifferentoperationregionwasprolongedfor moredurationforlower depthandhighersolarintens
Theexperimentalresultsof still–laboratoryandstill– solarwere comparedwithstill–theoreticalwithproposedmodel,fordifferentdepths anddifferentbasinmaterials. Theproductionrate,watertemperature,glass temperatureandglass–atmospherictemperaturedifferencevariationswere similar. The stillwith 0.5 cm depth was more productive. For still–laboratoryandstill–solar,from60^{O}C watertemperaturepointto maximum productionrate point,thestilloperationwasdifferentandthewater–glass temperaturedifferenceisinverselyproportional toproductionrate.
From thecorrelation graph forproduction rate,itwasobserved that,for higherwatertemperatures,the productionratewascomplexfunction water,glass,atmospheric, water–glasstemperaturedifferenceandglass–atmospherictemperaturedifference.Also,the proposedtheoreticalmodel predicted theproduction ratewithhigher deviation with actual. Hence, topredictthe productionrate accurately,athermalmodel,whichwasthe refinementoftheproposedmodel,wasestablishedandvalidated.

INTRODUCTION

1.1 THENEEDFORDESALINATION

Cleanpotablewateris abasicnecessityformanalongwithfoodand air. Freshwateris alsorequiredforagriculturalandindustrialpurposes. The main sourcesofwater arerivers, lakes andunderground water reservoirs. However,directusesof waterfromsuchsourcesarenotalwaysadvisable, becauseof thepresenceof higheramountofsaltandharmfulorganisms. The highergrowthratein world populationandindustriesresultedin alarge escalationofdemandforfreshwater.The naturalsourcecanmeetalimited demandandthisleadstoacuteshortageoffreshwater.Hence,thereisan issuetoessentiallytreatthesaltandcontaminatedwaterintopurifiedwater.

EXPERIMENTATION

4.1 EXPERIMENTATIONONWINDOW GLASSES

4.1.1 Experimentalsetup

The experimentwascarriedout usinga commerciallyavailable tracking typePhotovoltaic (PV) sun meter (Figure 4.1). The meterhad 0.36m 0.17msizePV paneltosensethesunradiation.Thepanelwas fixed onastandsothatitcanbesetatanyinclination withhorizontal.Thepanel stand wasmounted on a base with leveling screws. A displayunit was connectedwithPVpanel.Theunitwascalibratedtodisplaytheradiationin W/m^2.Theinstrumentmeasuresthetotalradiation,whenthe panelisexposed tosunlight. WhenthebeamradiationonthePVpanelis shaded,itmeasures diffusedradiation.A blackumbrellafixedonthemovableblackverticalpipe, placed5’abovethePVpanel,isusedasshadingdevice.Whenaglassis placedonthePV panel,thedisplay readstheradiationtransmittedthroughthe glass.

4.1.2 Experimentalprocedure

Theexperimentwasconductedduring NOV.2015toDEC.2015attheterraceof theMechanicalEngineeringDepartmentmainbuilding, M R K institute of technology,Kattumanarkoil(9°11'N,77°52'E). Thesunmeter wasplacedonthetable,sothatthe panelwasalongnorthsouthdirection.The levelscrewswereadjustedtobringthebaseofthepanelinperfecthorizontal position.Commerciallyavailablewindowpanelglassofdifferentthicknesses

2mm,3mm,4mm,5mmand6mmwereusedfortransmittanceanalysis. Totalanddiffusedradiationsweremeasuredforhorizontal,10, 2030and 40 degreeinclinationtowardsnorthandsouthplanewithandwithoutglasson thePVpanel.Theratiobetweentheradiationtransmitted(radiationreading withglass)andradiationreceivedat thetopsurface(radiationreadingwithout glass) isthe transmittance of the glass. Readings weretaken daily from morning6amtoevening6pmwithone-hourinterval.

1 Experimentalsetupofstill–laboratory

Asingle basindouble slope solar still has been fabricated with mildsteelplateasshowninFigure4.2.Theoverallsizesoftheinnerand outerbasinswere2.08m × 0.84m × 0.075mand2.3m × 1m × 0.25m, respectively. The gap between the inner and outer basin was air tightly packedwithricehusk. Theouterbasinwasmadeupofmildsteelsheet. The topwascoveredwithtwoglassesofthickness 4mm,inclinedat30°onboth

sidesusingwoodenframe.Theoutersurfaces werecoveredwithglasswool and thermocool insulation. Thecondensed waterwascollected intheV-shapeddrainage,providedbelowtheglasslowedgeonbothsidesofthe still. The condensatecollected wascontinuously drained through flexible hoseandstoredinameasuringjar. K–typethermocouples wereinserted throughaholeinthebasinsidewallforthemeasurementofthebasinwater, stillandcondensatetemperature.Fourthermocoupleswereplacedin the basin atdifferentlocations.Twothermocoupleswereplacedinboththe drainage,to measurethe condensatetemperature.Theholewasclosed withinsulating materialtoavoidthe heatandvapourloss.Mercurythermometer wasusedto measuretheatmospherictemperature.Anotherholewasprovidedforwater inlet.Throughthisholeasmalltubewasinserted,tosupplycompensation raw water continuously from storage tank using a measuring tube. The controlvalvesarrangementwas usedtokeepthe massofwaterinthebasin alwaysconstant.Byadjustingthecontrolval vesV1andV2,requiredquantity of rawwaterwasstoredinthemeasuringtube.WhenthesetwovalveskeptclosedandV3is opened,thewaterstoredinthemeasuringis suppliedtothe basin. Theheatingcoilof 2000Wwasplacedbelowtheinnerbasintosupply necessaryheat tothebasin. TheAC electricalpower wassupplied tothe heaterthrougha controlcircuit.Theinputpowerwasvariedusinga variable voltagetransformer.AnACdigitalwatt meterwasfittedwiththecircuitto measuretheinputpower.Figure4.3showsthephotographicviewofthestill –laboratory.

Experimentalsetupofstill–solar

Toconvertthe still- laboratoryintostill-solar,theheater,power supply,powermeasurementsystemandinnermildsteel basinwereremoved. The bottom ofthe still was leveled with 5 cm thick cement concrete to minimizeheatlossthroughthebasinandtospreadtheminimum depthof water uniformly as shown in Figure 4.4. The concretesurface was black paintedtoimprovetheradiationabsorptioncapacity.Thetotalanddiffused solarradiationsatthehorizontal,theplaneinclinedat30^o facingnorthand southwas measured using the calibrated photovoltaic type sun meter

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Thetemperaturesofwaterandcondensatewererecordedwiththe helpofcalibratedK-typethermocouplesincombinationwitha digital temperatureindicatorhavingaleastcountof 0.1^oC.Theambienttemperature wasmeasuredusingacalibratedmercurythermometerhavingaleastcountof

1^oC.Therawwaterinputwassuppliedthrougha measuringtubewithleast countof 10ml.Thedistillateoutputstillwasmeasured usingmeasuringjarof leastcount10ml.TheACpowerwasmeasuredusingdigitalwattmeterwith theleastcountof

1W.Thetotalanddiffusedradiationon30^{o}inclinedplane facingsouthandnorthweremeasuredusinga calibratedPhotovoltaictype sunmeterhavingaleastcountof 1W/m^{2}.Thediffusedradiationsoninclined surfacesweremeasured byshadingthebeamradiationonthephotovoltaic surface. The ambientair velocitywasmeasured with anelectronic digital anemometerofhavinga leastcount of 0.1m/swith±2%accuracyonthefull-scalerangeof0–15m/s.

4.2.3 Experimentalprocedure

4.2.3.1 Still-laboratory

Theexperimentonafabricatedstill–laboratorywascarriedoutat

Steam Laboratory, National Engineering College, Kovilpatti(9^{o}11'N,

77^{o}52'E),acityinsouthernIndiaduringJanuary2006toMarch2006.The heatinputwasgiventothestill usingheatingcoil.Twotypes of experiments werecarriedout.Inthefirst work,theheatinputwasvariedto matchwith respecttoactual solar radiationcondition.Forvariouswaterdepths this experimentswereconducted.In the secondwork,the experimentswere conductedforconstantdepthwithdifferentconstantpowerinputs.For agiven constantdepthofbasinwatercondition,theinputtotheheaterwasvariedfor every15minutesfrom0-775W/m^{2}between6amand12noonandfrom

775-0W/m^{2} between12noonand6pmtomatchwiththelocalaverage solarradiation condition (Anna Mani1980).Theheater wasswitched off duringnight.

Theexperimentswereconductedfor2cm,1.5cm,1cm, 0.5cmand

0.2cmwaterdepthsinthestillbasinforsamevaryingheatinputcondition

withoutfreeze.Forexperimenswithdepthof water0.5cmand0.2cm,a light blackcottonclothwereusedtospreadthewaterthroughtheentireareaof the basin.Forgivendepth,alltheobservationsweretakenfor24 hoursduration startingfrom6am.Thetemperaturesof theatmosphere,basinwaterandthe condensate werenoted for every 30 min. The watt meter reading and condensate collected onboth sideofthe still were also noted. Since, thethermocouplefixedontheglasscoverwill not readcorrecttemperatureduetosunradiationeffect,thecondensatetemperaturewasconsideredas glass temperature.

Theexperimentswereconductedwithalayer ofwaterequivalentto

0.2cmdepthinthebasinwithwick materialslikelightcottoncloth,lightjute clothandspongesheetof 2mmthicknessandsolidmaterialslikewashed naturalrockofaverage size3/8"x1/4"andquartzite rockofaveragesize 3/8".Thesewickandsolidmaterialswereusedtospreadthelayerof water throughtheentireareaofthebasin.

Thestillwas alsotested under various constant inputconditions withconstantbasindepthof1cm.Theheatis suppliedbytheheateruntilthe steadystateconditionwasreachedstill.Then thepowerwascutoffandthe stillwasallowedtocool naturallytoreachequilibriumstatewithatmosphere. The basin water temperature, condensate temperature and condensate collectedwererecordedforevery30minutes. Theexperimentswerecarried outfortheconstantinputpowersof300W,600W,900W,1200Wand 1500W.

4.2.3.2 Still–solar

The experiment with still – solar with concrete basin at actual sunshine condition was conducted at open terrace of the main block, Department of Mechanical Engineering, National Engineering College,

Kovilpatti. Theexperiments wereconducted duringJanuarytoApril2007. TheexperimentswerealsoconductedwithmildsteelbasinduringJanuary to April2008.

Experimentswereconductedinstill – solarwithconcreteandmild steelbasinforvariousdepthsof 8 cm,5cm, 2cm, 1cmand0.5cm. A light blackcottonclothwasusedinthebasintospreadthewaterwhenthewater depthis0.5cmforconcreteandmildsteelbasin.

Theexperimentswereconductedinstill–solarwithmildsteelbasin withvariousbasinconditions.Theexperimentswereconductedwithalayer of water and different wick and solid materials during August 2008 to October2008.Differentwickmaterialsusedinthe basinalongwith0.5cm depthof waterwerelightcottoncloth,lightjutecloth,spongesheetof 2mm thicknessandcoirsheetmadeupoffiberfrom coconutshell.Thedifferent solid materials used alongwith 0.5cmand0.75 cmdepth ofwaterwere washednaturalrockofaveragesize3/8”x1/4”andquartziterockofaverage size3/8.Thesewickandsolidmaterials wereused tospread thelayerof waterthroughtheentireareaofthebasin.Experimentswerealsoconducted with aluminiumrectangular fins in thebasin arranged inboth length and breadthwisearrangementscoveredwithlightcottonclothandjutecloth.

Theobservations weretakenfor24hoursduration, startingfrom

6amtonextday 5am.Thetotalradiationonhorizontalplane,atmospheric temperature,basinwater temperature,still airtemperature,condensate temperatureandthecondensatecollectedwerenotedforevery30minutes. Forevery 30minutes,thecompensatingrawwaterequaltodistillatecollected wassuppliedtothe basinfromstoragetank throughmeasuringtubeandthe controlvalvesarrangements.

CONCLUSION

Experimentswereconductedondifferentthicknesswindowglasses tostudyitstransmittancebehaviorforvarious solarradiation conditions. It wasfoundthat,thetransmittancewasindirectlyproportionaltothicknessof the glass, indirectly proportional to solar incidence angles and diffused radiationfractions.Thetransmittancemainl y dependedondiffusedradiation fractionathigherincidenceangles.Theregressionequationcouldbe usedto estimate transmittance of the glass at any location and at any time for differentradiationconditions.